PART I - ADMINISTRATIVE

Section 1. General administrative information

Title of project

Develop New Technology For Telemetry And Remote Sensing Of Fish Quality

BPA project number: 20012
Contract renewal date (mm/yyyy): ☐ **Multiple actions?**

Business name of agency, institution or organization requesting funding
Oregon Cooperative Fish and Wildlife Research Unit

Business acronym (if appropriate) OCFWRU

Proposal contact person or principal investigator:

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NPPC Program Measure Number(s) which this project addresses
Direct applicability concerning technology development: 4.2A, 4.3C.1, 4.3C.2; Examples of technology applicability, when developed: 5.6A.14, 5.9A.1, 6.1B.3, 6.1B.8, 6.1D.4, 6.1D.7, 6.1G.1, 7.1A.1, 7.2B.1.

FWS/NMFS Biological Opinion Number(s) which this project addresses

Other planning document references
United Nations Law of the Sea (Agenda 21, Chapter 17)

Short description
Develop, verify, and field test a new telemetry system (named "FIELD-OP") which is triggered by fixed or mobile transmitter stations to download real-time or stored position, depth, temperature, and fish quality data to receivers.

Target species
Adult salmon, though applicable to all mid-sized or larger fish and wildlife species, with miniaturization potential for smolt-sized individuals.

Section 2. Sorting and evaluation

Subbasin
Field testing will occur in the Willamette, Lower Mid-Columbia, John Day, and Deschutes subbasins, though this work is applicable to all subbasins in the Columbia River Drainage System.

Evaluation Process Sort

CBFWA caucus	Special evaluation process	ISRP project type
Mark one or more caucus	If your project fits either of these processes, mark one or both	Mark one or more categories
☒ Anadromous fish ☒ Resident fish ☐ Wildlife	☒ Multi-year (milestone-based evaluation) ☐ Watershed project evaluation	☐ Watershed councils/model watersheds ☐ Information dissemination ☐ Operation & maintenance ☐ New construction ☒ Research & monitoring ☐ Implementation & management ☐ Wildlife habitat acquisitions

Section 3. Relationships to other Bonneville projects

Umbrella / sub-proposal relationships. List umbrella project first.

Project #	Project title/description

Other dependent or critically-related projects

Project #	Project title/description	Nature of relationship

Section 4. Objectives, tasks and schedules

Past accomplishments

Year	Accomplishment	Met biological objectives?

Objectives and tasks

Obj 1,2,3	Objective	Task a,b,c	Task
1	Develop the telemetry system	a	Determine best implant location for fish quality probe and tag on fish
		b	Validate fish quality probe against current techniques, independent of telemetry system, in adult fish
		c	Perform engineering research and development for the new telemetry system

		d	Incorporate fish quality probe into new telemetry system
2	Test the new telemetry system under controlled conditions	a	Test all parts of the telemetry system for transmission, reception, accuracy, and durability independent of fish
		b	Perform on-fish tests of telemetry system's data transmission, reception, accuracy, and durability
3	Test the telemetry system under field conditions	a	Test fixed data-logging capabilities over long range
		b	Test mobile data acquisition
4	Answer an example research question to validate usefulness of telemetry system	a	Determine the relative effects of different dams and tributaries on adult spring chinook salmon quality

Objective schedules and costs

Obj #	Start date mm/yyyy	End date mm/yyyy	Measureable biological objective(s)	Milestone	FY2000 Cost %
1	10/1999	5/2001	MicroProbe validated; FIELD-OP developed	Yes	100.00%
2	10/2000	9/2001	FIELD-OP validated	Yes	0.00%
3	5/2001	3/2002	FIELD-OP tested in field	Yes	0.00%
4	5/2001	9/2002	Migration research completed	Yes	0.00%
				Total	100.00%

Schedule constraints
ESA permitting may constrain validation and field work.

Completion date
September 2002

Section 5. Budget

FY99 project budget (BPA obligated):

FY2000 budget by line item

Item	Note	% of total	FY2000
Personnel	Includes a research asst., grad. Student, and fish-culturist; all part-time	%12	39,660
Fringe benefits	Rate ranges from 1-52%, depending on position	%4	14,692
Supplies, materials, non-expendable property	Telemetry equipment	%1	6,000
Operations & maintenance	MicroProbes, sample analysis, fish holding, etc...	%5	19,050
Capital acquisitions or improvements (e.g. land, buildings, major equip.)			0

NEPA costs			0
Construction-related support			0
PIT tags	# of tags: 0		0
Travel	International and domestic	%2	8,500
Indirect costs	43%, excluding tuition, equipment, and subcontract >$25,000, for Oregon State University	%14	45,968
Subcontractor	Star Oddi for system development	%57	186,000
Other	Tuition	%1	3,820
		TOTAL BPA FY2000 BUDGET REQUEST	$323,690

Cost sharing

Organization	**Item or service provided**	**% total project cost (incl. BPA)**	**Amount ($)**
USGS-Biological Resources Division	15% PI's time (only FY2000 listed)	%2	30,000
Oregon State University	Administrative Assistant (only FY2000 listed)	%1	20,000
Star Oddi	Development Costs (includes other external sources; only FY2000 listed)	%63	646,000
		Total project cost (including BPA portion)	$1,019,690

Outyear costs

	FY2001	**FY02**	**FY03**	**FY04**
Total budget	$317,758	$255,501		

Section 6. References

Watershed?	**Reference**
☐	Block, B.A., H. Dewar, T. Williams, E.D. Prince, C. Farwell, and D. Fudge. 1998. Archival tagging of Atlantic bluefin tuna (Thunnus thynnus thynnus). Marine Technology Society Journal 32:37-46.
☐	Contreras-Sanchez, W.M. 1995. Effects of stress on the reproductive performance and physiology of rainbow trout (Oncorhynchus mykiss). M.S. Thesis. Oregon State University, Corvallis, Oregon.
☐	Contreras-Sanchez, W.M., C.B. Schreck, M.S. Fitzpatrick, and C.B. Pereira. 1998. Effects of stress on the reproductive performance of rainbow trout (Oncorhynchus mykiss). Biology of Reproduction 58:439-447.
☐	Cook, C.J. 1997a. Real-time measurements of corticosteroids in conscious animals using an antibody-based electrode. Nature Biotechnology 15:467-472.
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☐	Foster, L.B. and R.T. Dunn. 1974. Single-antibody technique for radioimmunoassay of cortisol in unextracted serum or plasma. Clinical Chemistry 20:365-368.

☐	Houston, A.H. 1990. Blood and circulation, p. 273-334. In C.B. Schreck and P.B. Moyle (eds.) Methods for fish biology. American Fisheries Society, Washington, D.C.
☐	ICES (International Council for the Exploration of the Sea), Anadromous and Catadromous Fish Committee. 1997. Report of the study group on ocean salmon tagging experiments with data logging tags. ICES Publication CM 1997/M:3. ICES, Copenhagen, Denmark
☒	ISG (Independent Scientific Group). 1996. Return to the river: restoration of salmonid fishes in the Columbia River ecosystem. Publication No. 96-6. U.S. Department of Energy, Northwest Power Planning Council, Portland, Oregon.
☐	Marshall, G.J. 1998 Crittercam: an animal-borne imaging and data logging system. Marine Technology Society Journal 32:11-17.
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☐	Maule, A.G., R. Schrock, C. Slater, M.S. Fitzpatrick, and C.B. Schreck. 1996. Immune and endocrine responses of adult chinook salmon during freshwater immigration and sexual maturation. Fish and Shellfish Immunology 6:221-233.
☒	NRC (National Research Council), Committee on Protection and Management of Pacific Northwest Anadromous Salmonids. 1996. Upstream: salmon and society in the Pacific Northwest. National Academy Press, Washington, D.C.
☐	Plotkin, P.T. 1998. Interaction between behavior of marine organisms and the performance of satellite transmitters: a marine turtle case study. Marine Technology Society Journal 32:5-10.
☐	Redding, J.M., C.B. Schreck, E.K. Birks, and R.D. Ewing. 1984. Cortisol and its effects on plasma thyroid hormones and electrolyte concentrations during seawater acclimation in yearling coho salmon, Oncorhynchus kisutch. Gen. Comp. Endocr. 56:146-155.
☐	Roby, D.D, D.P. Craig, K. Collis, and S.L. Adamany. 1998. Avian predation on juvenile salmonids in the lower Columbia River. Annual Report 1997. BPA and USACE, Portland, Oregon.
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☐	Strange, R.J. and C.B. Schreck. 1978. Anesthetic and handling stress on survival and cortisol concentration in yearling chinook salmon (Oncorhynchus tshawytscha). Journal of the Fisheries Research Board of Canada 35:345-349.
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PART II - NARRATIVE

Section 7. Abstract

We propose to develop a telemetry system (**F**ish **I**n **E**nvironment **L**ogging **D**ata-**O**vertly **P**hysiological: **FIELD-OP**) which includes a bi-directional tag, capable of measuring fish quality and environmental variables, being communicated with remotely, and transmitting stored data from onboard sensors. The fish quality (i.e. stress) sensor will measure *in vivo* and through time without handling after initial implantation. Other improvements of this system over current telemetry technology include the union of stored data with position data and the retrieval of stored data without the necessity of recapturing fish. Once developed, future application of this telemetry will allow a much less invasive understanding of affects the Columbia River system is having on adult fish quality, condition, and ultimately survival. This understanding will benefit the Columbia Basin Fish and Wildlife Program at a range of spatial scales by, for example, pinpointing problematic sections of individual dams or identifying bottlenecks to reproductive fitness in watersheds. Besides research, monitoring of the Basin to determine the effect of changes, such as dam removal, on fish quality and subsequent population numbers will be possible.

Development will proceed from initial subcontract work by a microelectronics telemetry company, and validation of the physiological fish quality sensor by experimental comparison to current radioimmunoassay techniques, to controlled experimental tests of the integrated system, and, finally, field tests of the system which includes answering a simple research question to confirm the benefit of this system. The proposed work entails three years for development, validation, and testing.

Section 8. Project description

a. Technical and/or scientific background

Wouldn't it be wonderful if the fish could tell us where bottlenecks affecting survival and/or reproductive fitness were in the Columbia/Snake basin? Numerous factors have contributed to the decline of anadromous salmonids in the Columbia River basin, including dam passage, habitat deterioration, poor ocean conditions, overfishing, and indirect human impacts such as hatchery-reared fish and the introduction, intentionally (e.g., smallmouth bass) and unintentionally (e.g., Caspian terns on dredge fill islands in the Columbia River estuary; Schreck *et al.*, 1993, 1997; Roby *et al*., 1998) of exotic predators (NRC, 1996; ISG,1996). These factors impact the quality (fitness; ability to survive at various life history stages and reproduce) of Pacific salmon. If we could accurately assess the direct effect of specific problem areas, we could better target management actions and fund expenditure toward those with the greatest impact, thereby ensuring greater reproductive capacity and, hence, greater population numbers. This proposal is for development of an innovative system that will provide both a history of environmental variables experienced by the fish as well as information on the quality of the fish consequent to location and these conditions.

Justification. We have established that stress has negative reproductive consequences in adult salmonids (Contreras-Sanchez *et al.*, 1998) and survivorship of juveniles (Schreck, 1981), and cortisol can provide an index of stress experience by salmonids during reproductive maturation (Maule *et al*., 1996; Contreras-Sanchez, 1995). Current telemetry systems and stress measurement techniques are not adequate to assess the effects of the river system on fish stress and quality through time while the fish is in the system. Telemetry systems used to study aquatic organisms (Stone and Kraus, 1998) fall into two general tag categories - ones that transmit constant signals to external receivers (Schreck *et al*., 1997; Deutsch *et al*., 1998; Martin and da Silva, 1998), and ones that store data for future downloading, at one (pop-up tags: Marshall, 1998; Westgate and Read, 1998; and archival tags: Sturlaugsson and Gudbjornsson, 1997; Block *et al.*, 1998; Sisak, 1998) or more points in time (satellite-linked tags: Plotkin, 1998; Westgate and Read, 1998). Systems vary in terms of how they collect data, but all suffer from limitations in size and life (continuous transmitters), recovery (archival tags), position information between recovery and downloading (pop-up tags and archival tags), subjection to animal behavior for data download, and inaccuracy in small bodies of water (satellite-linked tags). Extant methods available for assessment of stress or other quality measures require the collection of fish and direct tissue sampling (Schreck and Moyle, 1990). This has obvious limitations regarding where and when fish can be assessed in complex systems, and handling may cause additional stress which may skew results (Strange and Schreck, 1978; Maule *et al*., 1996). Presently, stress can only be measured at that one point where the fish is captured, and not throughout the system; multiple assessments from individual fish to get relative impacts of different parts of the river system are not now possible.

Telemetry and stress measurement problems are solvable with current technologies and can be integrated into one system. The tag we will develop will solve many telemetry problems by being energy and size efficient to a greater degree than other tags and by being able to *store* environmental and physiological data, *receive* signals from an outside wireless activator, and *transmit* wireless data to an outside receiver. These features eliminate: 1) continuous transmission of signals and power depletion, 2) need to recapture the tag or animal, 3) lack of position data, 4) dependence on the behavior of the animal for data transmission, and 5) accuracy issues associated with satellite-linked tags in freshwater systems. We will also incorporate an *in vivo* probe developed by Cook (1997a, 1997b) which, except for initial capture for implantation, allows continual measurement of quality (stress) in the field, without further handling. This sensor is non-lethal, will reduce sampling and laboratory time and costs, can easily be interchanged with sensors for other blood parameters (i.e., those indicative of maturational condition), and is very small (50-100 micron diameter), which, combined with the size efficiency of the new tags, will possibly allow use in juvenile salmonids.

Applications. Given traditional methods of tracking and measuring stress in fish, the incorporation of a sensor which remotely measures stress into the new telemetry system described above would vastly improve our knowledge of any system wherever fish quality is an issue. We will be able to not only know where a fish is or has been, but we will know how it "feels" in those places, and how they subsequently affect condition. Specific examples of questions answerable with this telemetry system are:

- As fish occupy different watershed habitats, as affected by land use practices, are there specific sites or conditions that affect fish quality?
- Do different flow regimes or spill levels affect fish passage?
- How do intra-dam variations affect fish quality?
- How do dams differ in their effect on fish (inter-dam variation in fish stress)?
- Will dam removal affect migration to spawning grounds and production of eggs?
- Are certain rearing/holding procedures in aquaculture or broodstock management more benign than others?

In addition, due to the small size of the probe and possible further miniaturization of tags, juveniles may be able to be tagged in the future, in which case we could answer:

- Are certain sites particularly stressful to rearing or outmigrant fish?

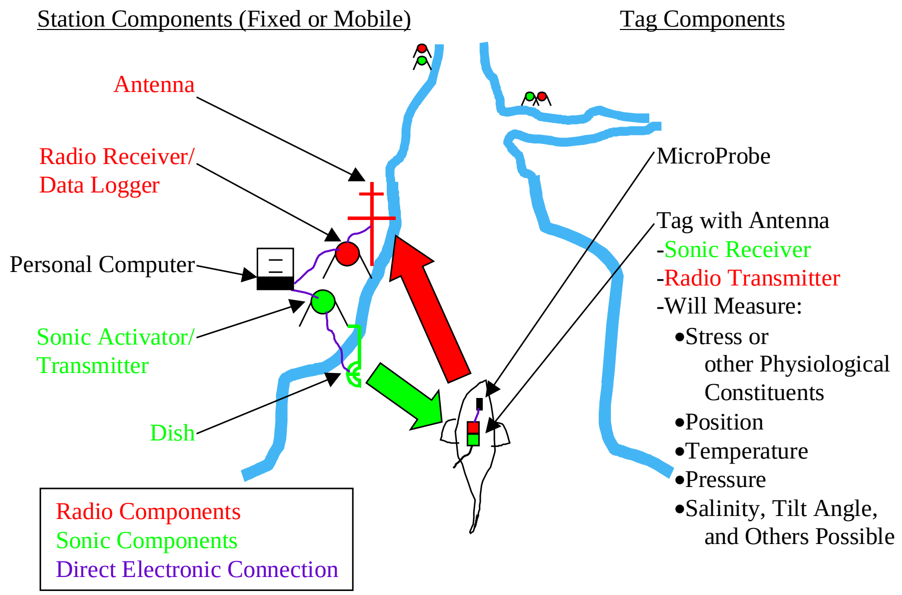
- Are current views of dam passage and barge transportation effects on smolts accurate, or has handling stress affected our views on these issues?
- Do different flow regimes or spill levels affect fish passage?
- In the estuary, what is smolt quality and is saltwater entry stressful?
- What is the delayed mortality from hydropower system passage in the estuary?
- Is there a relationship between juvenile stress and adult straying?
- Are hatcheries operating at acceptable levels of fish care?
- Are hatcheries releasing fish at optimal times for migration?

This telemetry system will be a tool for both research and monitoring, at a variety of different spatial scales, from very small (microhabitat, intra-dam, facilities) to large (watersheds, inter-dam). It will have wide-spread applications, give us the ability to understand numerous pressing issues relating to salmon recovery in the Columbia River Basin, and be a large step forward in fisheries biology and management.

Description. The proposed telemetry system will be named **F**ish **I**n **E**nvironment **L**ogging **D**ata-**O**vertly **P**hysiological (**FIELD-OP**). FIELD-OP consists of several components (see Figure 1). The two major parts to the system are surface-based (land or water) stations and the tag system. Surface-based stations include a computer to program components and retrieve data, an acoustic activator (transmitter) which "triggers" tags to transmit data, and a radio receiver which collects data transmitted from the tags. These stations will be located at dams or in watersheds where data collection is essential. Depending on the scientific question, the stations can be fixed and unoccupied, mobile and occupied, or a combination of the two.

The tag system will be able to take measurements at prescribed times from one or several sensors incorporated into its circuitry, store the resulting data, receive an acoustic (=sonic) signal to carry out commands or change sampling parameters, and transmit data via radio (=RF) signals. Integrating acoustic input and radio output on one tag has not been done before and will minimize the tag size and maximize battery life. Incoming signals (commands) will be shorter in duration than outgoing signals (data downloading). Thus, we can take advantage of acoustic waves, which are limited in duration due to acoustic noise present in a riverine system, to save tag battery power (=smaller size) for incoming signals. Less energy-efficient radio signals, which are not affected by river noise, will be used for the intermittent transmission of data. Sensors that are presently available include temperature, pressure, and the physiological fish quality probe (NOTE: depending on size, possible future sensors include salinity [for smolts in the estuary], tilt angle [giving vertical direction, a potential indicator of disorienting turbulence], and 3D position). The tag will be programmable by computer at the time of release for energy saving "sleep" modes, sampling intervals, and downloading parameters. Tag programming will be able to be modified by acoustic transmissions while in/on the fish. With this system, we will be able to know where a fish has been from fixed or mobile station locations, and what it experiences at and between these locations through the sensors.

Figure 1. Schematic of principle components of the system to be developed under this proposal. Diagram represents a tagged fish in a river with one tributary and three fixed stations (two in the distance and with less detail). Different signal types and components associated with types of signals are color-coded.



b. Rationale and significance to Regional Programs

The development of this project would forward the goals of the FWP by reducing scientific uncertainty (4.2A) and developing new technology for monitoring salmonid populations (4.3C.1 and 4.3C.2). After this system is developed, it would have wide applicability to most research and monitoring of adult, and possibly juvenile, salmonids, as well as other fish and wildlife, in both the current FWP and any future amendments to it. This will directly help the FWP achieve its systemwide goal of a healthy Columbia River basin through the indication and prioritization of problem areas which managers can then mitigate. An example of a specific measure this technology could be used for is the evaluation of tributary, mainstem, estuary, plume, near-shore ocean and marine salmon survival, ecology, carrying capacity and limiting factors (7.1A.1). Other measures where this technology could be applied include: 5.6A.14, 5.9A.1, 6.1B.3, 6.1B.8, 6.1D.4, 6.1D.7, 6.1G.1, 7.2B.1. The broad applicability of this tool will allow it to help carry out many of the FWP goals and objectives.

c. Relationships to other projects

The system developed by this work will be usable in a variety of projects addressing Fish and Wildlife Program needs. As a tool for assessing or testing quality of individuals, it could easily fit into almost any research or monitoring objective dealing with fish, mammals, or birds. The development work *per se* has no connections to current projects. However, the work does involve the cooperation of the following three different groups. All groups have agreed to the roles stated above. Letters of cooperation or collaboration are on file at OCFWRU and are available if needed. The groups are:

Oregon Cooperative Fish and Wildlife Research Unit (OCFWRU; a joint entity of Oregon State University, Oregon Department of Fish and Wildlife, the USGS-Biological Resources Division, the US Fish and Wildlife Service, and the Wildlife Management Institute) - group submitting proposal which will guide development of the system specific for the Columbia River Basin and perform all validation and testing (lab and field) for the MicroProbe and telemetry system.

Star Oddi - a microelectronics, engineering company based in Iceland with international experience in research and development of technologically-innovative telemetry systems for fish (*www.star-oddi.com*) which will be subcontracted by OCFWRU and develop the telemetry system described above. Star Oddi will also choose a subcontractor to develop the computer chip necessary for and at the heart of the proposed telemetry system.

HortResearch - one of nine Crown Research Institutes set up in New Zealand as private companies owned by the government, and the largest food research organization in New Zealand, will provide physiological sensors (already developed by them) to OCFWRU for testing and validation, and will work with Star Oddi on a licensing agreement for possible direct integration of the MicroProbe into Star Oddi's telemetry system. Star Oddi will work with HortResearch on possible improvement and miniaturization of their system as well. A formal agreement between the two companies will need to be made because of commercial, legal, and confidentiality concerns before direct integration can take place. Both parties have agreed to communication and cooperation, and favor mutual benefit.

d. Project history (for ongoing projects)

This is a new Bonneville proposal.

e. Proposal objectives

The proposed work is primarily developmental and much of it does not entail specific hypothesis testing. However, certain validations and tests will include statistically analyzable results. The anticipated fiscal years (FY) when the objective's work will take place are given in parenthesis.

1. Develop the telemetry system.
    a. Determine best implant location for fish quality probe and tag on fish (FY2000).
    b. Validate fish quality probe against current techniques, independent of telemetry system, in adult fish (FY2000).
        H_o: The MicroProbe is not able to document changes in stress in adult fish.
        H_o: Stress measurements do not differ between MicroProbe and traditional radioimmunoassay (RIA) techniques.
    c. Perform engineering research and development for the new telemetry system (FY2000, FY2001).
    d. Incorporate fish quality probe into new telemetry system (FY2001).
2. Test the new telemetry system under controlled conditions.
    a. Test all parts of the telemetry system for transmission, reception, accuracy, and durability independent of fish (FY2000, FY2001).
    b. Perform on-fish tests of telemetry system's data transmission, reception, accuracy, and durability (FY2001).
        H_o: Stress measurements do not differ between telemetry system and traditional radioimmunoassay (RIA) techniques.
3. Test the telemetry system under field conditions (FY2001?, FY2002).
    a. Test fixed data-logging capabilities over long range.
    b. Test mobile data acquisition.
4. Answer an example research question to validate usefulness of telemetry system (FY2001?, FY2002).
    a. Determine the relative effects of different dams and tributaries on adult spring chinook salmon quality.
        H_o: Migrating adult salmon stress levels do not vary as they move through the lower mid-Columbia River system.

f. Methods

Objective 1. As testing and validating of the MicroProbe (*Tasks 1a* and *1b*) takes place at OCFWRU to determine final configuration of the entire system, which will be accomplished in *Task 1d* by HortResearch and Star Oddi, development of the telemetry system will be concurrently taking place "in-house" at Star Oddi in Iceland (*Task 1c*). Descriptions of tasks follow.

Task 1a. The best implant location for both the tag and the probe will be determined for adult chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*O. mykiss*). The ideal location for the probe, which must be inserted directly into a blood vessel (Cook, 1997a), is the dorsal aorta (Houston, 1990). Possible internal locations for the tag are the peritoneal cavity (body cavity), dorsal sinus, or stomach (Winter, 1983). External locations include attachment on the back near the dorsal fin (Winter, 1983). In determining the location for both the probe and the tag, we will take into account the following factors: physiological or environmental viability (will they be able to measure, transmit, or receive as designed?), ease of implantation or surgical procedure for both the fish (short- and long-term recovery) and personnel, physical viability (will they stay in place through time?), and tag-probe electronic connection limitations. Once the optimal locations for placement of both the tag and the probe are determined based on these factors, the final design of the tag-probe system can be completed and implemented in *Task 1d*. All surgical and/or attachment procedures will be documented and will be done using proper IACUC protocols.

Task 1b. In order to validate that the MicroProbe is reliable, we must compare it to our current published technique (Foster and Dunn, 1974; as modified for use with salmonid plasma by Redding *et al*., 1984). This will be done by OCFWRU through two experiments. For both validation experiments we will use spring chinook salmon and rainbow trout. This is because cortisol levels (indicative of stress) are naturally elevated for migrating adult salmon (Maule *et al*., 1996), and we need to validate stress measures over as broad a range of circulating levels as possible. Non-migratory rainbow trout are more readily available and serve as a good generic "salmonid model". They will allow validation at lower levels of cortisol, and because ripe adults are available at different times throughout the year, they afford a broad temporal window of experimentation. Rainbow trout will also represent the anadromous steelhead morph. Returning spring chinook salmon will be obtained as early as possible (e.g., Willamette stock should be available in early April). Trout and salmon will be tested at OCFWRU's Fish Performance and Genetics Laboratory in Corvallis, OR.

The first experiment will simply test whether the MicroProbe can detect changes in fish stress levels. This will be done by inserting MicroProbes into five individuals of each species, allowing a recovery period, and initiating a stress to the fish. The stress will either be a confinement (water drawdown) or capture (netting) stress. MicroProbe readings will be taken by HortResearch's telemetry system into which the MicroProbe is currently incorporated (note that this is not the one being developed by Star Oddi). Stress levels after recovery will be compared to stress levels at the time of induced stress to see if the MicroProbe can detect a difference in cortisol levels (t-test).

The second experiment, contingent on verification of functionality in the first experiment, will determine the comparability of MicroProbe measures to standard radioimmunoassay (RIA; Foster and Dunn, 1974; as modified for use with salmonid plasma by Redding *et al*., 1984) measures of stress. In this experiment, there will be four treatments with three replicates per treatment and five fish per replicate for each species (N=60 fish/spp). The treatments will be fish with and without MicroProbe implantation, and with and without stress. Fish from all treatments will have blood drawn from them, as necessary for the RIA. The treatments without the MicroProbe will have cortisol levels determined by standard RIA techniques alone. The treatments with the MicroProbe will have cortisol levels determined by RIA and MicroProbe. Comparison of RIA values between treatments will show the effect of the MicroProbe on the fish, and comparison of values between MicroProbe and RIA in and between treatments will show the accuracy of MicroProbe readings. Fish in each treatment will be handled similarly, except with regard to stressors, which will be indicated by treatment. Stressors applied to fish will be realistic in nature (ie., mimic going up a fish ladder or experiencing thermal problems). MicroProbe readings will be taken continuously throughout the experimental time period, which will have the added benefit of allowing us to determine the affect of handling stress on RIA measures. Blood samples for RIA analysis will be taken after a recovery period and after a stressor, as in the first experiment. Replicates are individual fish holding tanks (N=3/treatment); if no tank differences exist, individual fish will be used as replicates (N=15/treatment). Chinook and rainbow trout experiments will not be done concurrently due to space limitations. Data will be analyzed by ANCOVA, with treatment and measure type as factors and sample time/stress level as covariate.

Task 1c. The research and development (R&D) of the telemetry system will involve a series of discrete steps intended to minimize technical risk and anticipate areas of extra effort. Star Oddi will conduct the R&D, except step 1, which will include OCFWRU assistance specific for the Columbia River system. The steps are:

1. *Specifications* **-** outline technical performance and determine steps to achieve this

2. *Simulation and Verification* - test digital and analog components before designing integrated circuit
3. *R&D of the Integrated Circuits* - develop integrated circuits which must be custom-made for state-of-the-art microsystems (i.e., tags). The custom-made integrated circuit, which will be smaller and more reliable than market circuits, includes:
   - 3a. *Digital (Microprocessor) Circuit* - construct an integrated circuit with a low power microprocessor which will always be active, keeping track of time and activating measurements at pre-programmed times
   - 3b. *Analog Circuit* - construct an integrated circuit with low power analog circuitry, turned on for taking measurements only
4. *R&D of Sensors* - develop or integrate acoustic receiver, pressure, and temperature sensors (Note: the stress probe is not included in this step; see *Task 1d*).
5. *R&D Software* - develop microprocessor software to operate the microsystem, manage data memory, control sensor measurements, and receive outside commands. User friendly software for the personal computer will be developed.
6. *R&D Communication Link* - design radio link meeting FCC (Federal Communications Commission) and ETSI (European Telecommunication Standards Institute) specifications.
7. *R&D Mechanical Encapsulation* - develop, mold, and test (destruction test) a hydrodynamically-shaped, polycarbonate plastic housing for the tag, which is easy and light for the fish to carry
8. *Acoustic Transmitter Station* - develop an acoustic transmitter station for communication with the microsystem which has an optimized range for the Columbia River system
9. *RF Receiver Station* - develop an optimized radio receiver station for acquisition of data from the microsystem.

Task 1d. Technical and biological factors need to be considered when integrating the MicroProbe into the telemetry system. The method of technical integration depends on electronic features of each system (MicroProbe and tag) and development by Star Oddi and HortResearch. Biologically, the integration must incorporate the findings from *Task 1a.* Thus, this task will occur after *Tasks 1a* and *1b*, but will be anticipated in *Task 1c*.

Objective 2. The integrated telemetry-MicroProbe system will be thoroughly tested under controlled conditions after *Objective 1* is completed with and without fish.

Task 2a. Tests of the system will be conducted as it is being developed to assure proper function. As described in *Task 1c*, each individual component of the telemetry system will have its own specifications, simulation, development, and testing. Once the system is complete, both Star Oddi and OCFWRU will perform whole system tests prior to field use in *Objectives 3* and *4* to verify specifications and integrated function. This includes testing of command transmission and reception, data transmission and reception, battery life, submersion ability, and software interface.

Task 2b. In order to test the accuracy of the telemetry system, as well as the effect of the tag and probe on fish, we will repeat the experiment from *Task 1b* using the new integrated tag-probe telemetry system, with modifications in duration and number of stresses. This experiment will be longer in order to test data storage capabilities of the tag. Experimental period will be representative of times an adult spring chinook spends in the Columbia/Snake system. We will also apply multiple stresses, also mimicking Columbia/Snake system features (e.g., encountering sequential dams), in order to gain ancillary knowledge about recovery and additive effects. Fish will be monitored for tag and probe integrity through time. Data will be analyzed by repeated measures ANOVA. See *Task 1b* for further details of experimental design.

Objective 3. The purpose of this objective is primarily to verify range of both the acoustic and radio components of the system in the Columbia River Basin (mainstem and tributaries). The parts of *Tasks 3a* and *3b* described below will be done employing drogues and using boats. *Task 4a* will serve the dual function of completing *Tasks 3a* and *3b* with fish, and being the "dress rehearsal" for future studies.

Task 3a. The range of acoustic and radio transmissions to and from the tag will be verified. Given specifications in development, we should have a good idea of range, but because there are so many variables that determine range, we will verify it in different parts of the system with different basin profiles (depth, width, surrounding features, and geomorphology). We will use fixed stations on land and boats moving upstream approximating movement of migrating adult salmon (taken from literature; e.g., Schreck *et al.*, 1994) to thoroughly document range of reception and transmission for tags. Boat passes will vary by speed (within reasonable variation), depth of tag, depth of water, and horizontal distance from fixed station. Tags will be placed on submersible drogues simulating fish orientation and tag location. Acoustic interference from the boat will be tested and minimized with tow lines for the drogues, though boat activity must be taken into account for system range. The fixed station will be tested for reception location (higher is better for radio reception) and its ability to handle multiple tags passing at the same time. Precise distance measurements will be achieved using GPS data measured in GIS software. Visual field observations and meticulous notes on conditions of tag passage will be used to confirm electronic estimates of distance.

Task 3b. The ability of mobile telemetry to locate tags in the basin will be established. Types of mobile telemetry which will be tested include: boat, plane (for radio)/boat (for acoustic) combination, or truck. Two coordinated teams will determine how well fish (drogues) can be found over long river stretches. One team (the "fish") will place drogues at various locations throughout the river. The other team (the mobile unit) will try to find these drogues and download data from them. From this exercise we will learn: 1) how often we have to "sample" the river for tags, based on acoustic range of the telemetry system, and 2) what type of mobile unit of the three described above is most efficient. We will also vary the programmable tag energy-conservation ("sleep") mode, which sacrifices communication with stations for increased battery life. This will give us important knowledge on how to program these tags for implantation into migrating adult salmonids.

Objective 4. Information gained from *Tasks 3a* and *3b* will be used to complete on-fish tests of the system in *Task 4a.* We will know how to program the telemetry system, where to place fixed stations for best tag acquisition, and how to sample with the mobile station, in order to answer a relevant research question which will also validate the usefulness of this new system.

Task 4a. To determine how different parts of the lower mid-Columbia River affect migrating spring chinook salmon, we will tag 10 fish and monitor their movement upstream. Fish will be tagged at Bonneville Dam and fixed telemetry stations will be placed at The Dalles Dam and John Day Dam. We will also have a mobile telemetry station tracking fish to monitor their progress and possible movement into the Deschutes or John Day River systems. In another part of this work, 10 separate fish (five per dam) will be tagged for fixed location releases near our fixed monitoring stations at the dams. These fish will provide a smaller scale comparison between the two dams and a comparison to the fish moving through the system on their own (on a larger movement scale). Blood samples will be taken at the time of tagging for all fish, to verify MicroProbe function and provide a baseline estimate of fish quality in addition to that provided by the MicroProbe. This experiment may be performed with more fish depending on results from *Task 3a* concerning capacity of fish/tags the fixed telemetry stations can accommodate. It will be repeated several times to understand migratory or temporal variability. Data will be analyzed between locations in the system (dams and tributaries) and times with ANCOVA (time as the covariate). The results will indicate how different dams or multiple dam passage affect fish condition as they move into tributaries.

Limitations

A development project always contains technical risk, especially if the system is new and has never been used in rivers. This proposal is for research and development to overcome these risks, and, as development engineers, Star Oddi is well equipped to do this. Areas in R&D, and otherwise, that currently need resolution are:

- the integrated sonic and radio antenna, where efficiency is limited by size of the tag
- the pietzo ceramic in the acoustic receiver, where sensitivity is limited by size of tag
- the range of the RF system must be optimized and will be affected by RF reception station's antenna coverage, fish velocity, and tag RF transmitter power output
- the acoustic system range must be optimized and will be affected by geomorphology of river basins which cause acoustic "noise", output power of acoustic transmitter, acoustic receiver sensitivity and

size (tag component), fish velocity, and duration of acoustic transmissions (shorter minimizes echoes/noise and transmission lag).

- tag pre-programming, which must be done correctly for the tags to be able to "wake-up" at the correct locations in the river for reception and transmission of signals; continuous monitoring will reduce battery life
- the integration of the MicroProbe and tag, which needs to be researched and developed on the technical as well as the economic/business front
- MicroProbe life, which is currently about two weeks (Cook, pers. comm.) - sufficient for some assessments, but not those for longer time scales
- obtaining ESA permits for working with adult spring chinook salmon, though we see no reason why this research would not warrant permitting, especially given its non-lethal nature and the small number of fish required.

g. Facilities and equipment

Given the current state of products and technology at the major cooperating groups, we have confidence that we will be able to achieve the proposed work. Examples of these groups' qualifications are:

OCFWRU - has been conducting physiological research in the Northwest and on the Columbia River for over 20 years. Carl Schreck, the principal investigator, pioneered stress assessment techniques in fish (Schreck, 1972, 1981; Schreck and Moyle, 1990) and has guided OCFWRU radiotelemetry work for over 10 years (Schreck *et al*., 1993; Schreck *et al*., 1994; Schreck *et al*., 1997). Facilities available include a state-of-the-art physiology laboratory set up for RIAs, a computer laboratory for data analysis (including GIS software), and a fish research facility (Fish Performance and Genetics Laboratory, Corvallis, OR) which can rear and hold salmonids under optimum conditions. Field equipment for this work is largely existent; two telemetry-prepped 20' Alumaweld workboats, GPS equipment, and towing/work vehicles are examples of items which are in OCFWRU's inventory. Equipment needed for this project includes a field computer and HortResearch radiotelemetry gear, as described in the next section.

Star Oddi - a microelectronic telemetry company which currently produces state-of-the-art Data Storage Tags for marine and anadromous species, which are capable of storing measured data for download upon retrieval (see *www.star-oddi.com*). These tags have been used in a variety of marine research (Thorsteinsson, 1995; ICES, 1997; Sturlaugsson and Gudbjornsson, 1997; Thorsteinsson and Matreinsdottir, 1998). Their engineers will provide the expertise to produce this next-generation telemetry system. Star Oddi will provide various simulators and electronic equipment. Some items will need to be purchased to produce the tags and other components of the system (see next section). Star Oddi will subcontract chip manufacture and tag housing mold tooling (see next section). The equipment necessary for the silicon circuit prototype development and production will be provided by the chip manufacturer.

HortResearch - Christian Cook of HortResearch developed the MicroProbe which measures blood hormone levels in farm animals (Cook, 1997a; 1997b). Currently the probe is being adapted for use in fish and is incorporated into a proprietary telemetry system (Cook, personal communication).

h. Budget

OCFWRU - personnel budgets reflect the amount of work to be done in each fiscal year. The first year, when MicroProbe validation and coordination between groups is the primary work, OCFWRU will have no full-time personnel. Subsequent years have a full-time research assistant and a full-year, half-time graduate assistant. A part-time fish culturist is also included for rearing and holding of experimental and "validation" fish. Large items to be purchased include a field computer (FY2001), MicroProbes (all years), and HortResearch proprietary telemetry equipment for initial MicroProbe validation (FY2000). All other operating costs include cortisol assays, fish holding, field housing, boat gas, boat maintenance, telecommunications, copying, project supplies, and other general expenses. Domestic travel is for attending review meetings and conferences for dissemination of findings. International travel is for travel between Iceland, New Zealand, and the United States for planning and testing by relevant parties. The subcontract to Star Oddi is described below. A 4% inflation rate is assumed for each year.

Star Oddi (subcontractor) **-** costs here include personnel (four engineers full-time the first year; two the second year), supplies, international travel for trips to the chip manufacturer, equipment, internal overhead costs, and subcontracts (primarily to the chip manufacturer). The last year of work for Star Oddi includes construction of telemetry stations and training of OCFWRU personnel for testing in the Columbia River. Given the extremely expensive and high-tech nature of this development, Star Oddi has secured internal and external funding ($1,017,000/3 yr.) which will be in addition to that currently proposed.

Section 9. Key personnel

Carl B. Schreck

Project Duties	<u>Principal Investigator</u> • Oversee all aspects of project management
Expertise	Research in environmental physiology of fish including stress, health and reproductive quality, and behavior of salmonids. Project management. Publication.
Current Position	<u>Leader</u>, Oregon Cooperative Fish and Wildlife Research Unit, Biological Resources Division-U.S.G.S., *and* <u>Professor</u>, Dept. of Fisheries and Wildlife, Oregon State University. Corvallis, Oregon
Education	University of California, Berkeley A.B.-Zoology, 1966 Colorado State University M.S.-Fisheries Science, 1969 Ph.D.-Physiology/Biophysics and Fisheries, 1972
Experience	• 25 years research in Columbia River system on juvenile and adult salmonids in streams, rivers, reservoirs, dams, and estuary • 30 years research and project management leading to nearly 200 publications • Editor or editorial board of 5 scientific journals; presently *General and Comparative Endocrinology*, *Diseases of Aquatic Organisms*, and *Aquaculture* • Formerly Assistant Profssor- Fisheries, Virginia Polytechnic Institute and State University
Recent Publications	Schreck, C.B., B.L. Olla, and M.W. Davis. 1997. Behavioral responses to stress. p. 745-170. <u>In</u>: G.W. Iwama, J. Sumpter, A.D. Pickering, and C.B. Schreck (eds.). Fish stress and health in aquaculture. Cambridge University Press., Cambridge. Schreck, C.B. 1996. Immunomodulation: endogenous factors. p. 311-337. <u>In</u>: G.W. Iwama and T. Nakanishi (eds.). Hoar and Randall's Fish Physiology, vol. 15. Academic Press, New York. Contreras-Sanchez, W.M., C.B. Schreck, M.S. Fitzpatrick, and C.B. Pereira. 1998. Effects of stress on the reproductive performance of rainbow trout. (*Oncorhynchus mykiss*). Biol. Reprod. 58:439-447. Maule, A.G., R. Schrock, C. Slater, M.S. Fitzpatrick, and C.B. Schreck. 1996. Immune and endocrine responses of adult chinook salmon during freshwater immigration and sexual maturation. Fish and Shellfish Immunol. 6:221-233. Davis, L.E. and C.B. Schreck. 1997. The energetic response to handling stress in juvenile coho salmon. Tran. Amer. Fish.Soc. 126:248-258.

Project Duties	Project Leader • Oversee and organize all OCFWRU activities • Coordinate work between cooperating groups • Perform administrative and reporting requirements for the project
Expertise	Current and past experience as a project leader and in aquatic and fisheries research have provided necessary skills and knowledge to perform as project leader and coordinator for this integrated telemetry and physiology work.
Current Position	Oregon Cooperative Fish and Wildlife Research Unit (OCFWRU) Oregon State University, Dept. of Fisheries and Wildlife. Corvallis, OR Project Leader/Faculty Research Assistant (1.0 FTE). January 1998 - present • prepares and completes proposals, reports, manuscripts, and presentations • designs and analyzes research • hires, trains, organizes, and supervises personnel • performs budget administration • coordinates and interacts with a variety of other agencies • prepares for and oversees field and lab work involving fish radiotelemetry and physiology
Education	The Ohio State University Columbus, OH April 1991 - September 1993 Master of Science in Aquatic Ecology Advisor: Roy A. Stein University of Notre Dame Notre Dame, IN August 1986 - January 1990 Bachelor of Science Major: Biological Sciences/Ecology
Experience	UMass Dept. of Landscape Architecture and Regional Planning. Amherst, MA Research Assistant. September 1996 - May 1997 The Ohio State University, Aquatic Ecology Laboratory. Columbus, OH Research Associate. January 1995 - August 1996 Computer Administrator. January 1995 - August 1996 Lecturer and Teaching Assistant. January 1995 - April 1995 Graduate Research Associate/Project Leader. April 1991 - September 1993
Certification	U.S. Dept. of the Interior, Motorboat Operator Certification Course, April 1998 U.S. Dept. of the Interior - OAS, Basic Aviation Safety Course (B-3), April 1998 American Red Cross, Standard First Aid, March 1998 American Red Cross, Adult CPR, March 1998 Oregon State University, Radiation Safety Course, September 1998
Relevant Job Report	Schreck, C.B. and T.P. Stahl. In Prep. Evaluation of migration and survival of juvenile salmonids following transportation. Draft Annual Report 1998, Project MPE-W-97-4. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.
Recent Publications	Stahl, T.P., G.P. Thiede, R.A. Stein, E.M. Lewis, M.R. Austin, and D.A. Culver. 1996. Factors affecting survival of age-0 saugeye *Stizostedion vitreum vitreum* X *S. canadense* stocked in Ohio reservoirs. North American Journal of Fisheries Management 16:378-387. Stahl, T.P., and R.A. Stein. 1994. Influence of larval gizzard shad (*Dorosoma cepedianum*) density on piscivory and growth of young-of-year saugeye (*Stizostedion vitreum* X *S. canadense*). Canadian Journal of Fisheries and Aquatic Sciences 51:1993-2002.

Sigmar Gudbjornsson
Managing Director, M.Sc.E.E. • StjⅡrnu Oddi ehf • Reykjavik, Iceland

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Expertise

Sigmar Gudbjornssson manages Star Oddi engineer resources. He has taken part in international R&D projects since 1983. His role has been that of development engineer and project manager and he has founded two R&D firms which are active leaders in their own fields.

Education

Alborg University of Denmark
Masters Degree in Engineering, M.Sc.E.E., 1993

Experience

Dancall a/s (DK) 1983 - 1986, development engineer of radio frequency products and project manager

T-com a/s (DK) 1987 - 1992, original founder, R&D engineer manager of cellular products; After the firm showed remarkable results in developing cellular telephones for the world market, the firm was bought by the multinational Korean concern, Maxon. Having served Maxon as a consultant for two years (from 1991 to 1992), Sigmar Gudbjornsson moved to his home country and joined Stjornu Oddi.

Stjornu Oddi ehf (IS) 1985, original founder, director and engineer manager; The engineers of Stjornu Oddi have been working in close co-operation with biologists, from the Icelandic Marine Research Institute and the Fresh Water Institute, designing microsystems for tagging fish. This work has given us valuable experience and expertise in researching and developing future generations of such microsystems.

Publications

Sturlaugsson, J. and Gudbjornsson, S. 1997. Tracking of Atlantic Salmon (Salmo salar L.) and sea trout (Salmo trutta L.) with Icelandic Data Storage Tags. Pages 52-54 in Boehlert, G.W., editor. Application of acoustic and archival tags to assess estuarine, nearshore, and offshore habitat utilisation and movement by salmonids. NOAA Technical Memorandum. NOAA-TM-NMFS-SWFSC-236. 2 p.

Jonsson, P.M., Johannsson, S.H., Oskarsson, G. and Gudbjornsson, S. Diving Behaviour of Atlantic Puffin (Fratercula arctica) Monitored by Microelectronic Data Storage Tags (DST). In preparation.

Sigmar Gudbjornsson's personal view is that in all R&D projects of this complexity there will be difficult phases. At these times, it is up to the experienced co-ordinator and developers to find simple solutions. Stjornu Oddi has shown in previous projects that they are capable of this task.

The engineers at Stjornu Oddi all have previous experience from R&D and manufacturing in Denmark as co-ordinators, production engineers and development engineers. The engineering team and the international network of engineers Stjornu Oddi has established, cover all the necessary aspects of such an R&D project. When the project is selected, Stjornu Oddi will add resources by employing engineers that have co-operated in the project development of our microsystems. The use of external development resources to support the internal resources gives us the opportunity to employ the best engineers for the job. These are engineers we have experience with and know to be some of the best in their field.

Stjornu Oddi is a small but effective R&D firm, where flexibility and expertise are our strongest advantages in the development of products. We are in the business of supplying microsystems for monitoring environmental parameters to our customers. In order for our business to grow and thrive, we need to provide our consumers with new and better products. Therefore, it is very important to us that this project be successful.

Section 10. Information/technology transfer

This work will produce a telemetry system which will be able to be used to accomplish objectives of the Fish and Wildlife Program, improve salmon populations, and will be applicable for scientists and managers throughout the world. Results will be presented at meetings as requested by Bonneville, at professional meetings, and through publications in peer-reviewed literature.

Congratulations!